

Measurement of Nicotine in Building Air as an Indicator of Tobacco Smoke Levels

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Humans apparently differ greatly in their sensitivity and tolerance to tobacco smoke, thereby creating conflicts in the workplace. Resolution of conflicts in a large office complex at the authors' institution required an objective measure of smoke levels. A gas chromatographic technique was devised for collection and analysis of nicotine concentrations in the building air as an indicator of tobacco smoke pollution. Segregation of smokers and nonsmokers in the large office complex still resulted in substantial exposure of the nonsmoker to tobacco smoke, although a gradient of exposure was certainly observed. Passive tobacco smoke consumption in the smoking area of the office complex was calculated to be equivalent to 1.1 cigarettes per 8-hr period, and nicotine density in this area was 1.96 $\mu\text{g}/\text{m}^3$. The restriction of smoking to a foyer area outside the office complex resulted in a slow but eventual reduction in nicotine concentrations in the office complex. Observed "background" nicotine concentration levels corresponding to 4 to 7% of those encountered in smoking areas demonstrate that central air circulation systems and people movement increase the nicotine level throughout all rooms of a building, regardless of the smoking policies of an individual office complex. Recent documentation of the relationship between passive smoking and cancer, heart disease, pulmonary dysfunction, and allergic responses argues for restriction of smoking to building exteriors.

Introduction

In recent years, increasing attention has been focused on the health consequences of passive or "second-hand" smoking. A number of reports in the literature form the basis of this concern. These reports include increased occurrences of such medically-documented conditions as allergic reactions (1,2), respiratory and visual irritation (3), diminished pulmonary function (4,5), cardiovascular disease (6), and lung cancer (7-9).

A heightened awareness on the part of the passive smoker to these hazards has inevitably led to increasing conflict among workers, especially in enclosed work environments. The least contentious and most widely practiced solution to the problem of passive smoking, between the extremes of doing nothing on the one hand and limiting smoking to building exteriors on the other, is to attempt the segregation of smokers and nonsmokers in some configuration within the practical limits of the enclosed building environment. Such segregation is now practiced with increasing frequency, and whether or not it is effective in substantially

reducing the health hazards of the nonsmoker to tobacco smoke is an important question which should be addressed.

Because of a serious conflict between smokers and nonsmokers in a major office complex at our institution, we were encouraged to develop a relatively simple method to quantitate the measurement of tobacco smoke in the building air. This we did by measuring nicotine, a chemical species uniquely found in air as a product of tobacco combustion. The method developed involved the condensation of nicotine from building air upon a cold glass surface followed by its extraction into methanol and measurement by on-column gas chromatography.

Experimental Methods

Sample Collection

Nicotine aerosols at specific building locations were sampled by placing an 8.9 cm diameter Petri dish upon a 7.6 cm diameter (surface) cold plate (model TCP-2, Thermoelectrics Unlimited, Inc.) adjusted to its coldest operating temperature (approximately -10°C) (Fig. 1A). Nicotine has a boiling point of 247°C . Therefore, its vapor pressure is sufficiently low that losses from the cold surface, once condensed from the aerosol (probably

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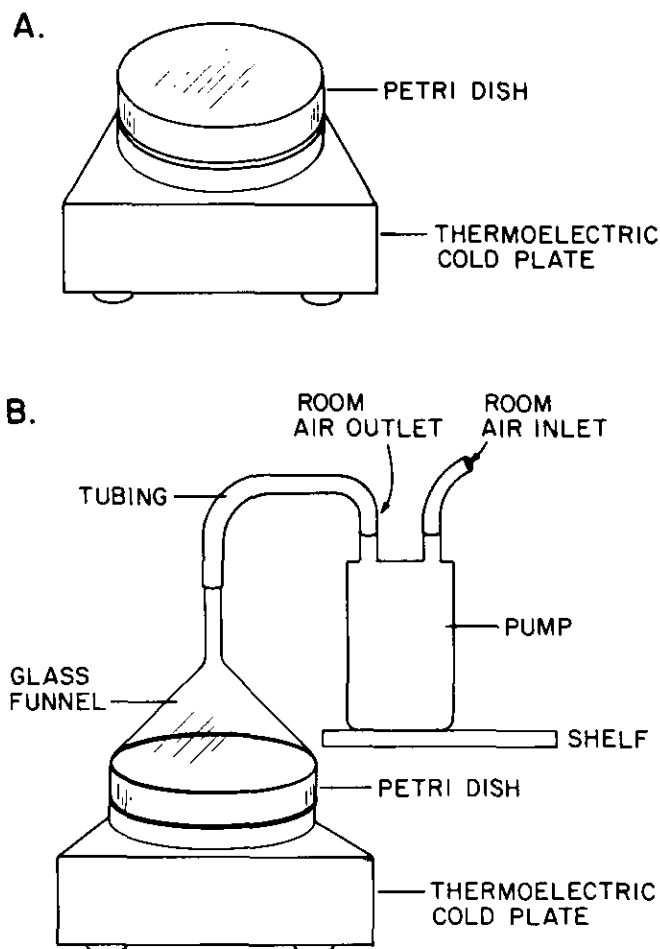


FIGURE 1. Sample collection methods: (A) nicotine trapped in cold Petri dish (8.9 cm diameter) placed on top of thermoelectrically cooled surface (7.6 cm diameter, Model TCP-2, Thermoelectrics Limited, Inc.); (B) a small air pump used to move air actively over the surface of the cold Petri dish set atop the thermoelectric cooling unit.

dispersed on dust particles), are negligible. The measured collection time depended upon the apparent density of smoke in the sampling area. In general, sampling times of 1 or 2 hr in areas of heavy smoking and 6–8 hr in nonsmoking or limited-smoking areas, were sufficient for reproducible nicotine analyses. All except one of the results reported in Table 1 were obtained by this method.

The sampling time may be reduced at least one-third by employing a small air pump to move air actively over the surface of the Petri dish. The air pump may be connected to a funnel inverted over the Petri dish to focus air onto the cold surface (Fig. 1B). The funnel itself, being cold as a result of its contact with the Petri dish, forms an additional surface for the precipitation of nicotine and must be washed with methanol to extract the nicotine. The device can also be used to "smoke" cigarettes; this permits a rough comparison between the amount of nicotine found in mainline cigarette smoke and that found in building air.

Sampling Locations

Four sampling locations were set up in an administration building and one within a chemistry building on the University of California at Davis campus. Sampling locations 1, 2, and 3 formed a gradient between smoking and no-smoking areas within a large 92×70 ft partially-partitioned L-shaped office complex (Fig. 2). Smoking was confined to the area indicated. Sampling station 1 was in the middle of the smoking area. Sampling station 2 was well within the nonsmoking area of the room and sampling station 3 was as far removed as possible from the smoking area. The fourth location was a designated nonsmoking area on another floor in the same building. Sampling location 5 was in a separate building in a nominally "no smoking" laboratory on the fourth floor. Both buildings are centrally air conditioned with 80% recirculation of air.

Nicotine Analyses

The Petri dishes were covered after the collection period and taken to the laboratory for analysis. The moisture collected along with the nicotine was evaporated just to dryness at 40°C with the dish covered with a circle of Whatman No. 1 filter paper (to reduce the possibility of further nicotine contamination). The surface of the Petri dish was rinsed thoroughly with 1 mL of Spectro-grade methanol and the solution transferred to a graduated 15-mL conical centrifuge tube with a Pasteur pipet. Depending upon the concentration of nicotine in the methanol, the samples were applied to the column of the gas chromatograph directly or evaporated to 0.1 mL.

Standard Curve

A standard curve for nicotine was constructed by the application of $1\ \mu\text{L}$ samples of nicotine (MCB Inc., Cincinnati, OH) dissolved in Spectro-grade methanol, by direct on-column injection. Linearity over a wide concentration range was observed (Fig. 3).

Gas Chromatography

The analyses were conducted on a Hewlett Packard 5710A gas chromatograph with a nitrogen-phosphorus (N-P) detector, retrofitted with an on-column injector and containing a $30\ \text{m} \times 0.25\ \text{mm}$ fused silica column coated with DB-1. The detector was maintained at 300°C and supplied with 3 mL/min hydrogen, 50 mL/min air, and 30 mL/min nitrogen make-up. The column, on-column injector, and fused silica needle syringe were all from J & W Scientific Inc., Rancho Cordova, CA. Injections were made directly on-column, using a $10\text{-}\mu\text{L}$ syringe with a 17-cm fused silica needle. The $1\text{-}\mu\text{L}$ sample was injected into a room-temperature portion of the column with the oven temperature at 40°C . Immediately after injection, the oven temperature was raised

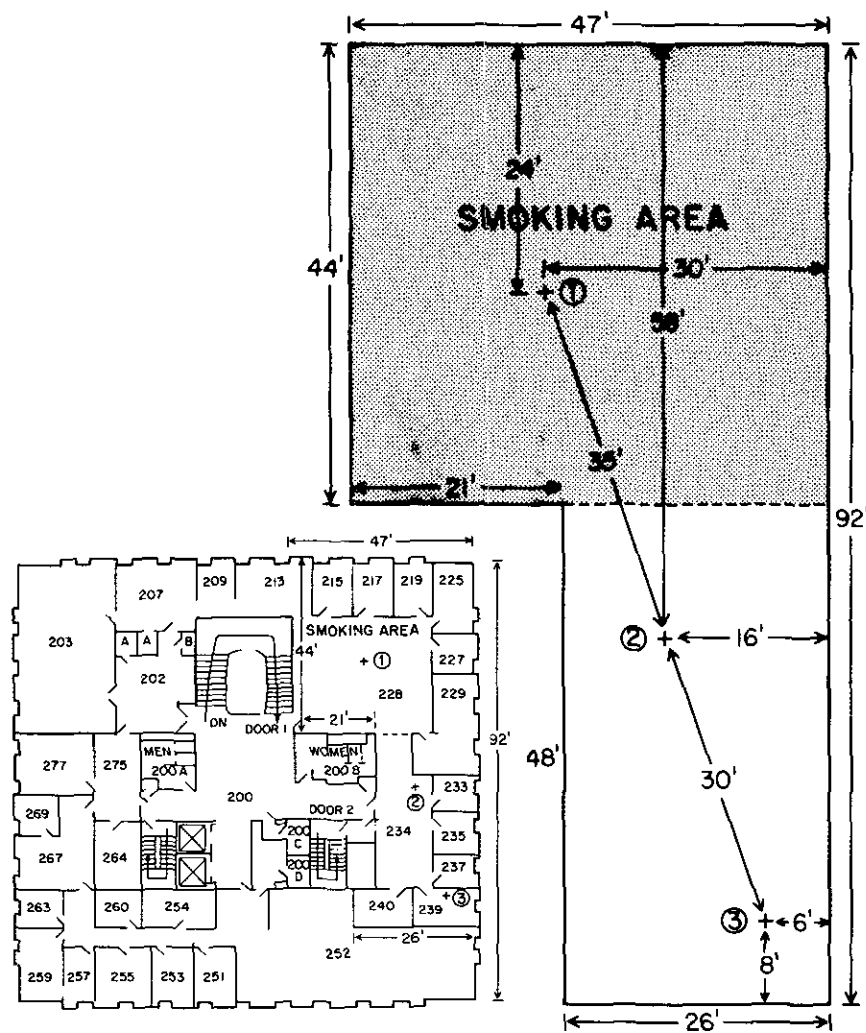


FIGURE 2. Schematic drawing of large office complex showing location of smoking area and of sample collection positions. (A) The area, consisting of rooms 209 to 240, represents the large office complex. + (1), + (2) and + (3) show positions of sampling. Note positions of doors 1 and 2. Smoking was permitted in Rooms 213 and 228 only. (B) Expanded area diagram showing distances between the three sampling positions.

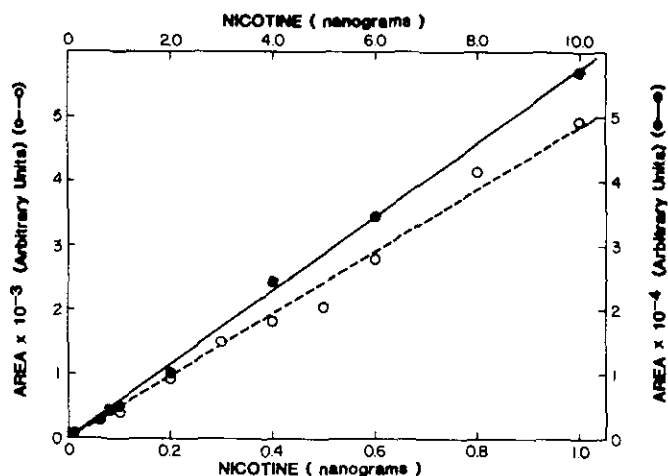


FIGURE 3. Standard curve for nicotine amounts. A 1- μ L aliquot of the required concentration was injected directly onto the capillary column as described in the text. The area is in arbitrary units as measured by an automatic integrator: (○) 0.1–1 ng nicotine; (●) 0.1–10 ng nicotine.

at a maximum rate (ca. 30°C/min) to 180°C and maintained. Detector response was fed to a Hewlett Packard 5880A for processing; voltage offset was 10%, and the attenuation was 2⁵. Each series of runs was standardized by using a 1- μ L sample containing 1×10^{-10} g/ μ L of nicotine in methanol.

Results

Figure 3 is a standard curve for a nicotine range of 0.1 to 10 ng. A value of 0.1 ng of nicotine represents the practical limit of detection for the instrument used. Higher amounts of nicotine (4 to 10 ng) gave a 16% higher response than did 10 times lower concentrations. The area under each curve is expressed in arbitrary square units as indicated by an integrator response.

Table 1 summarizes the results of nicotine analyses at the various sampling stations as indicated. Since the collection times and exposed surface area for collection are known, the results are reported in picograms (10^{-12}

Table 1. Nicotine levels in various locations in a large office complex with a restricted smoking area, in no-smoking locations and after periods of ban on smoking.

Sampling date	Sampling location	Nicotine collected, pg/m ² - min (average \pm SD) ^a	% of control value
Smoking in location 1 only of large office complex (Figure 2)			
2-16-83	1	134 \pm 10.	100 ^b
2-17-83	2	39.2 \pm 7.3	29.2
2-22-83	3	23.1 \pm 0.1	17.2
No smoking policy originally			
2-23-83	4 ^c	4.5 \pm 0.1	3.4
2-24-83	5 ^d	6.6	4.9
Ban on smoking location 1 of large office complex			
2-25-83	1, 1st no smoking day	29.1 \pm 2.3	21.7
2-28-83 ^e	1, 2nd no smoking day	32.5 \pm 1.8	24.3
Smoking permitted after 2-28-83 in location 1 of large office complex			
3-11-83	1	126 \pm 12.	94.0
3-11-83	1, pump collection	180 \pm 7.	134
Ban on smoking in location 1 of large office complex			
3-18-83	1, after 7 days	34.4 \pm 4.7	25.7
3-18-83	2, after 7 days	13.9 \pm 4.5	10.4
3-18-83	3, after 7 days	1.7 \pm 1.3	1.3
3-25-83	1, after 14 days	9.8 \pm 2.0	7.3
3-25-83	2, after 14 days	26.9 \pm 11.0	20.1
3-25-83	3, after 14 days	4.7 \pm 0.1	3.5
4-27-83	1, after 47 days	9.1 \pm 0.6	6.8
4-27-83	2, after 47 days	9.1 \pm 0.8	6.8
4-28-83	3, after 47 days	5.7 \pm 0.6	4.3
5-2-83	2, after 51 days, adjacent door open	4.9 \pm 0.2	3.7
5-3-83	2, after 52 days, adjacent door closed	5.5 \pm 0.1	4.1

^aThe standard deviations indicate the precision of the GC method in analyzing for nicotine. Insufficient samples were collected at each location to permit adequate determination of precision in collecting samples.

^bControl value.

^cDesignated nonsmoking area on another floor in the same building.

^dIn different building in a nominally "no-smoking" laboratory on the fourth floor.

^eMaintenance work was performed outside location 2 the previous day; whether the workers smoked was not determined.

g)/per square meter per minute (pg/m²-min). There is one average number (11 March) which is a comparison between the pump and the plate only collection methods. This permits a comparison of nicotine precipitation values with air volume values.

Discussion

Nicotine Analysis

In this study we employed a direct on-column technique for application of nicotine to the capillary column. While there are reports in the literature of greater sensitivity for nicotine analysis, the variability observed in the measurements necessitated the use of an internal standard such as quinoline or *N*-ethylnornicotine (10). The demonstrated good reproducibility over the range of 0.1 to 1 ng without the use of an internal standard is sufficient sensitivity for the modes of collection employed here. The only variability encountered in the analyses occurred when variable volumes of either standard or unknown nicotine solutions were applied in the direct on-column technique. Larger volumes are especially demanding of good injection technique and can yield variable results. For this reason only 1- μ L samples were applied to the column.

We observed a major carryover of nicotine in glassware that had not received special washing. It is

absolutely essential that glassware and syringes be scrupulously cleaned prior to each use. Nicotine is a pervasive component of building air (due to central air circulation systems), whether or not the occupants of a particular room smoke. The technique employed in our laboratory was one of washing all glassware used in the collection and analysis with soapy water followed by rinsing in distilled water and finally in ethanol. The glassware was dried quickly in an oven and placed inside polyethylene bags until used. Capillary syringes used in on-column injection were washed repeatedly in methanol between all standard and unknown injections and 1- μ L samples of Spectro-grade methanol were injected on-column from the syringe to verify an absence of nicotine carryover.

Sampling Techniques

Two sampling techniques were employed in this study. Samples collected on 11 March by the plate only method gave nicotine levels of 70% (126 \pm 11 pg/m²-min) of the value collected by pumping air over the plate (180 \pm 7 pg/m²-min). This ratio of 70% was remarkably constant for several comparisons made between these two methods.

One advantage of the pump method is that by calibrating the pump (knowing the precise volume of air moved across the plate per unit time), and assuming

that 100% of the nicotine is precipitated onto either the cold plate or cold funnel, one can calculate the amount of nicotine per unit volume of room air. For example, in the experiment of 11 March, where pump collection of room air nicotine yielded 180 ± 7 pg/m²-min, the pump was activated for 188 min and moved air across the plate at a rate of 91.6 mL/min. Therefore, the concentration of nicotine at that specific sampling location was 1.96 µg/m. This value compares quite favorably with other published values (1–10 µg/m) for nicotine concentrations in smoky environments (11,12) obtained by filtering and concentrating techniques, which probably resulted in incomplete recovery of nicotine (13).

The pump method also permits a rough correlation between nicotine levels of room air and full stream tobacco smoke by having the pump air inlet "smoke" a cigarette. Such measurements indicated that the smoking area of the large office complex contained nicotine levels on 11 March such that an 8-hr inhabitation would result in passively smoking the equivalent of 1.1 cigarettes. This value is roughly equivalent to those reported by other workers, who measured the effect of passive smoking in smoky environments (14,15). These workers measured nicotine in the blood.

The pump method was developed after the study of smoke levels in the large office complex was well underway by the plate method. Since the primary purpose of the study was to obtain an objective measure of smoke levels in the office and because of the sensitivity of all involved, the study was continued with the plate method.

Nicotine Concentration Gradients

Table 1 gives the nicotine concentrations measured at the five sampling locations. Location 1, the area in which four smokers were segregated, had the highest nicotine precipitation rate of the sampling areas. The precipitation rate of 134 ± 10 pg/m²-min corresponded well with sampling on other dates (see 11 March) at the same location when smoking was permitted. The 11 March concentration of 126 ± 12 pg/m²-min corresponded to a pump-measured volumetric determination of 1.96 µg/m³. This smoking area served as the relative basis (100%) with which all other areas were compared (the control value).

Sampling location 2 was positioned 35 ft away from sampling location 1 and approximately 24 ft into the nonsmoking area of the office complex. The nicotine concentration in the area (39.2 ± 7.3 pg/m²-min) was 29% of the value found in the smoking area, demonstrating substantial carryover into the nonsmoking area. Sampling location 3, another 30 ft removed into the nonsmoking area and in a partitioned subroom area, had nicotine concentrations of 23.1 pg/m²-min, which was 17% of the control value. Sampling location 4, a declared nonsmoking room on another floor of the same building, had a nicotine level of 4.5 pg/m²-min, which was 3% of the control value. This measurable nicotine value resulted either from random intrusion or non-

compliance by smokers or from circulation by the central air conditioning system from rooms which permitted smoking. A room in a separate building where no smoking was permitted gave a value of 6.6 pg/m²-min.

Nicotine Concentration Changes Following Ban on Smoking

The four smokers in the smoking section of the large office complex were asked to stop smoking in the office complex for a 2-day experimental period. Smoking was permitted in a large foyer immediately outside the office complex and separated by a closed door (Door 1, see Fig. 2). The door was opened frequently by the pedestrian traffic flow. Nicotine levels dropped in the smoking area to 21.7 and 24.3% of the control value after 1 and 2 days of no smoking, respectively. The relatively high value of nicotine in the air after 2 no-smoking days is either a reflection of nicotine persistence in localized environments (in fabrics, curtains, walls) or noncompliance with the prohibition.

Institution of a 2-week no-smoking period still gave a relatively high nicotine level in locations 1 and 2 (Table 1). At the end of the first week the nicotine values were: location 1, 25.7%; location 2, 10.4%; and location 3, 1.3% of the control value. At the end of the second week of no smoking, the nicotine values decreased substantially at location 1, but were high at location 2 (20.1%) of the control value. Sample variation in location 2 was substantial and it was noted that maintenance work was carried out near location 2 (outside Door 2, see Fig. 2) the previous day. Whether or not the workers involved were smokers was not determined.

A permanent prohibition of smoking in the large office complex was enacted on 4 April, and nicotine measurements were made on 27 and 28 of April. Nicotine measurements in previous smoking area 1 and the adjacent area 2 had dropped further but were still higher than values measured in the original nonsmoking areas (locations 3, 4, and 5). The reasons for this persistence are not understood. It is possible air movement patterns from the foyer (smoking area) into the office complex with frequent pedestrian traffic led to higher than expected values. In conjunction with air movement patterns, it was found that leaving Door 2 (Fig. 2), which leads to the foyer area, open had no impact on measurable nicotine concentrations at location 2 (samples dated 2 and 3 May). The results obtained from days in which Door 1 into the smoking area foyer was left either closed (first no-smoking week) or open (second no-smoking week) were inconclusive on this point.

Finding of measurable nicotine concentrations, ranging from 4 to 7% of that in a smoking area, in locations of an office complex far removed from smoking areas is a cause of concern. It indicates that all occupants of a building with a common air circulation system share the burden of passive smoking, regardless of the particular restrictions imposed within individual areas and sup-

ports the observation by Russell and Feyerabend (16) that "most urban nonsmokers have measurable amounts of nicotine in body fluids for most of their lives."

The health consequences of passively smoking at levels equal to 4 or 5% of that which occurs in a smoking environment is not known. A nicotine level of 5% of the control smoking environment would be equivalent to smoking 0.05 of a cigarette per 8-hr period. There is an impressive and well-documented list of the hazards of passive smoking. It is reasonable to assume, in the absence of evidence to the contrary, that limited exposure to cigarette smoke leads to some increase, in relation to a nonsmoking environment, in those ailments shown to be related to passive smoking (pulmonary dysfunction, cardiovascular disease, allergic responses, and lung cancer). Given the increasing concern articulated in recent years with respect to increasing health care costs and the increased cost of air conditioning in a smoking environment, the limiting of smoking to building exteriors in the workplace may be a logical option which should be seriously explored.

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REFERENCES

1. Speer, F. Tobacco and the nonsmoker. *Arch. Environ. Health* 16: 443-446 (1968).
2. Zussman, B. M. Tobacco sensitivity in the allergic population. *J. Asthma Res.* 11: 159-167 (1974).
3. Schmidt, F. Health risks of passive smoking. *World Smoking Health* 3: 19-24 (1978).
4. Tager, I. B., Weiss, S. T., Rosner, B., and Speizer, F. E. Effect of parental cigarette smoking on the pulmonary function of children. *Am. J. Epidemiol.* 110: 15-25 (1979).
5. White, R. J., and Froeb, F. H. Small-airways dysfunction in nonsmokers chronically exposed to tobacco smoke. *N. Engl. J. Med.* 302: 720-723 (1980).
6. Aronow, W. S. Introduction to smoking and cardiovascular disease. In: *Proceedings of the Third World Conference on Smoking and Health*, American Cancer Society and NIH, Bethesda, MD, Vol. 1, 1976, pp. 231-236.
7. Hirayama, T. Non-smoking wives of heavy smokers have a higher risk of lung cancer: a study in Japan. *Brit. Med. J.* 282: 183-185 (1981).
8. Miller, G. H. The Pennsylvania study on passive smoking. *J. Breathing* 41: 5-9 (1978).
9. Miller, G. H. Lung cancer: a comparison of incidence between the Amish and non-Amish in Lancaster County. *J. Ind. State Med. Assoc.* 1983: 121-123 (1983).
10. Jacob, P., Wilson, M., and Benowitz, N. L. Improved gas chromatographic method for the determination of nicotine and cotinine in biologic fluid. *J. Chromatogr.* 222: 61-70 (1981).
11. Hinds, W. C., and First, M. W. Concentrations of nicotine and tobacco in public places. *N. Engl. J. Med.* 292: 844-845 (1975).
12. Weber, A., and Fischer, T. Passive smoking at work. *Int. Arch. Occup. Environ. Health* 47: 209-221 (1980).
13. Holzer, G., Oro, J., and Bertsch, W. Gas chromatographic-mass spectrometric evaluation of exhaled tobacco smoke. *J. Chromatogr.* 126: 771-785 (1976).
14. Hoegg, U. R. Cigarette smoke in closed spaces. *Environ. Health Perspect.* 2: 117-128 (1972).
15. Folliart, D., Benowitz, N. L., and Becker, C. E. Passive absorption of nicotine in airline flight attendants. *N. Engl. J. Med.* 308: 1105 (1983).
16. Russell, M. A. H., and Feyerabend, C. Blood and urinary nicotine in non-smokers. *Lancet* 179-181 (1975).